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The first record of an audible sound produced by a ghost moth, *Phassus* (Hepialidae) from Costa Rica

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Abstract. Sound production in lepidopteran adults has been reported in at least 13 families. The majority of these families produce ultrasonic sounds that are inaudible to humans. Here we report the first record of an audible sound produced by a *Phassus* sp. (Hepialidae) from Costa Rica. The sound is clicking or creaking-like, produced as the moth raises its abdomen dorsally (bending the abdomen backwards). The mechanism of this sound production is unknown, but supposed to be a case of stridulation. As the moth raised its abdomen, blue iridescence patches (likely ornamented by structural colors) on the dorsum were observed. The clicking sound is composed of two main parts which varied in frequency and duration. Inferred from the brief observation, the raising of the abdomen and sound production are possibly used for defense against natural enemies.

Keywords: Costa Rica, defensive behavior, Lepidoptera, Neotropical, stridulation.

Introduction

Sound production in adult Lepidoptera is known from at least 13 families, such as Cossidae, Papilionidae, Hesperiidae, Nymphalidae, Pyralidae, Crambidae, Saturniidae, Sphingidae, Uraniidae, Notodontidae, Erebidae, Nolidae, and Noctuidae, all of which are in the infraorder Heteroneura (Lees, 1992 & references therein; Heller & Krahe, 1994; Skals & Surlykke, 1999; Minet & Surlykke, 2003; Smetacek & Smetacek, 2007; van Nieukerken, *et al.* 2011). The sounds are used in courtship, intraspecific and interspecific communication (Surlykke & Gogala, 1986; Spangler, 1988; Alcock *et al.*, 1989; Lees, 1992; Heller & Krahe, 1994; Alcock & Bailey, 1995; Greenfield, 2014 & references therein), and defense against predators (Blest *et al.*, 1963; Møhl & Miller, 1976; Vallin *et al.*, 2005). The characteristics of these sounds and the body parts involved in sound production vary between families, genera, and at species levels, revealing multiple origins of sound production mechanisms (Conner, 1999; Greenfield & Weber, 2000). Human audible sounds, usually between 20 and 5,000 Hz, are documented in some species of the day-flying whistling moths (Noctuidae: Agaristinae) in Australia. Males of *Hecatesia thyridion* Feisthamel produce a percussive sound while in territorial flight (Bailey, 1978; Surlykke & Fullard, 1989) and males of *Platagarista tetrapleura* (Meyrick) produce a whistling sound in flight which is audible from a 20–30 m distance (Common, 1990). Many cracker butterflies *Hamadryas* spp. (Nymphalidae: Biblidinae) produce cracking sounds while in their territorial flights (Monge-Nájera *et al.*, 1998; Yack *et al.*, 2000). During territorial flights at dusk, males of *Letis mycerina* (Cramer) (Noctuidae: Ophiderinae) produce sharp cracking sounds somewhat similar to those of *Hamadryas* spp. (K. Nishida, pers. observation 2003). However, most of the sounds produced in adult Lepidoptera are ultrasonic, generally above human-hearing range between 20,000 and 125,000 Hz (Greenfield, 2014 & references therein). For example, in the family Crambidae, the species *Symmoracma minoralis* (Snellen) (Nymphulinae) produces sound via genital organs (Heller & Krahe, 1994), while in *Ostrinia furnacalis* (Guenée) sounds are produced by rubbing wing scales against the thorax scales (Nakano *et al.*, 2009).

There is a record of an audible sound produced in a defensive context, in the moth *Dudusa sphingiformis* Moore (Notodontidae: Dudusinae). The adult while

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perching raises the abdomen in a jabbing form and produces a rather loud 'crick' or 'creaking' sound that is audible from ca. 50 cm distance (Smetacek & Smetacek, 2007; A. Kubota, pers. comm. 2012).

Sound production in the family Hepialidae (Exoporia: Hepialoidea) was previously unknown (D. Davis, D. Wagner & J. Grehan, pers. comm., 2011). Hepialidae, known as the ghost moths, is one of the most plesiomorphic groups of Lepidoptera. Distributed worldwide, there are approximately 600 described species (Nielsen *et al.*, 2000; van Nieukerken *et al.*, 2011). Mielke & Grehan (2012) recognized 125 species in 30 genera from the Neotropics. Approximately 20 species have been found in Costa Rica (Chacón & Montero, 2007). In the Neotropics hepialids are one of the least studied moth groups, thus there is very little information on their biology and there still remain undescribed species (J. Grehan & C. Mielke, pers. comm., 2011; Mielke & Grehan, 2012). Although many species are nocturnal, and several montane and arctic species are diurnal, the majority appear to be crepuscular in courtship, mating, and laying (dropping) eggs (Wagner & Rosovsky, 1991 & references therein). Hepialid larvae in general are internal or concealed feeders, constructing tunnels in roots, tree trunks, stems, or leaf litter (Grehan, 1989).

One of the major Neotropical genera is *Phassus* Walker, 1856. There are 12 described species, including 6 species in *incertae sedis* position, distributed from Mexico to southern Brazil (Mielke & Grehan, 2012; Grehan, 2013). Three named species have been recorded from Costa Rica, viz. *P. aurigenus* Pfitzner, 1914, *P. costaricensis* Druce, 1887, and *P. huebneri* (Geyer, [1838]) (Nielsen *et al.*, 2000).

Here we describe and illustrate the behavior of sound production in a ghost moth, *Phassus* sp. A spectrogram of the produced sound is provided and a short video clip (13 seconds) of the sound and behavior is available online (see Results section).

Materials and methods

The observation and recording were conducted in Sector Pittier (09°06'35"N, 82°93'50"W) at 1600 m a.s.l., of La Amistad International Park, Cerro Pittier in Cordillera de Talamanca, Puntarenas Province, Costa Rica, on February 27, 2010. The climate of the habitat (biotic unit) is considered 'tropical very humid with 3 or 4 months of dry season' according to Herrera & Gómez (1993) and the life zone is classified as 'lower montane rain forest' according to Bolaños et al. (1999). This mature montane forest is dominated by large oak trees (*Quercus* spp.) in the canopy, and ferns, palms and small bushes in the understory.

The sound was recorded using a Marantz PMD 661 solid-state digital recorder (accuracy: 16-bit; sampling rate: 44.1 kHz on WAVE format) with a Sennheiser ME66/K6 shotgun microphone. Behavior was videotaped using a Nikon D5000 photographic camera with a Nikkor 55-200mm f/4-5.6G lens. Sound recordings were deposited in Laboratorio de Bioacústica, Escuela de Biología, Universidad de Costa Rica (UCR01419).

We analyzed the sounds using a combination of sonogram, power spectrum, and wave form spectra in Raven Pro 1.4 (Cornell Lab of Ornithology, Ithaca, NY, USA). This approach allowed us a more accurate measurement of the frequency and duration characteristics (Redondo *et al.*, 2013). We used the following set up to obtain the measurements: a temporal resolution of 5.8 ms and a frequency resolution of 188 Hz (settings: Hann window; 256 kHz sampling, and 50% overlap). In each sound produced we measured: 1) minimum frequency (Hz), 2) highest frequency (Hz), 3) frequency of maximum amplitude (Hz), 4) duration (s), and 5) average entropy (μ: energy). We classified the sound in two parts based on the visual characteristics of the spectrogram. We report measurements as average ± standard deviation.

We were unable to collect, identify, and study the *Phassus* species in detail due to the conditions of our research permit. However from the images we have, the *Phassus* species we observed is quite similar to *P. basieri* Schaus, 1890, *Phassus huebneri* (Geyer, [1838]), or *Phassus triangularis* Edwards, 1885 (Grehan, pers. comm., 2011; Grehan, 2013). Consulting further with J. Grehan and C. Mielke (experts on the family Hepialidae), they suggested that it might also be an undescribed species.

Results

Description of the sound production behavior

At approximately 8 a.m., the *Phassus* sp. (n = 1) was found perched on a fern frond using its forelegs, at ca. 50 cm above ground. The middle legs were held loosely in the air and the hind legs were retracted, positioned parallel to its thorax and base of the abdomen (Fig. 1A). When we approached the individual 20 cm or closer, it started to pull itself up vigorously using the forelegs, simultaneously raising its abdomen dorsally, i.e. bending the abdomen backwards (Fig. 1B). The sound production occurred at the beginning, as it raised the abdomen (video link: http://www.kenjinishida.net/videos/phassus.html). The sound was 'zizi' or 'gigi', somewhat like a

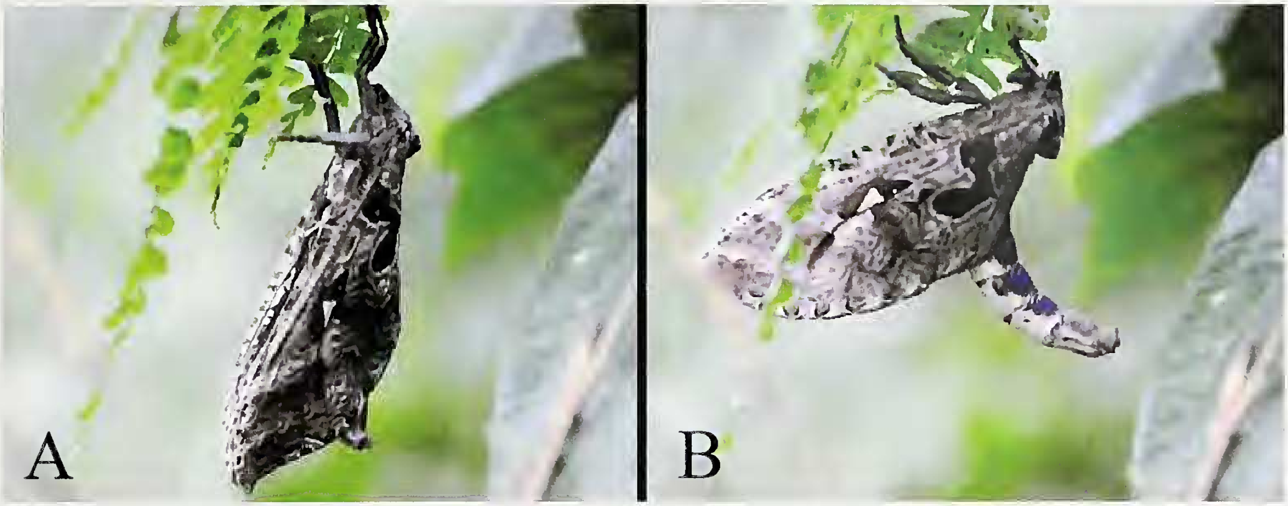

Figure 1. **A)** *Phassus* sp. resting on a fern frond, **B)** same individual raising its abdomen as response to the observer's approximation. These images were obtained from the video clip posted online at: http://www.kenjinishida.net/videos/phassus.html.

dull clicking, creaking or 'stridulation'. The raising and lowering of the abdomen lasted about 1 s each and occurred approximately every 2 s. The moth continued to repeat this movement for approximately 2 min. Slight movements of the hind leg tarsi were observed prior to raising of the abdomen.

As the moth raised its abdomen, patches of blue iridescence became visible on the dorsum of each anterior part of abdominal segment. However, depending on the angle, this blue iridescence was not always visible. We were unable to determine the sex of the observed individual.

Description of the sounds

We measured 23 clicking sounds produced by the *Phassus* moth. Each sound was composed of two parts (Fig. 2). The introductory part was composed of two or three discrete elements, and the duration of each was 0.002 ± 0.0004 s. The main part was a series of close elements (sometimes overlapping each other) and it was difficult to measure each of these. The duration of the main part was 0.08 ± 0.009 s. The minimum frequency was 666.9 ± 113.0 Hz for the introductory part and 393.1 ± 36.9 Hz for the main part. The highest frequency was 9463.1 ± 473.8 Hz for the introductory and 9328.9 ± 823.0 Hz for the main part. The frequency of maximum amplitude was 4021.1 ± 582.9 Hz for the initial and 5103.3 ± 483.7 Hz for the main part. The entropy was 5.86 ± 0.04 μ for the introductory and 5.64 ± 0.04 μ for the main part.

Discussion

Regarding the behavior of the *Phassus* sp. studied here, a somewhat similar behavior has been observed in *Dudusa sphingiformis* (Notodontidae) which is distributed from the Himalaya towards the Korean peninsula into Tsushima Island, Japan (Jinbo *et al.*, 2013). Smetacek & Smetacek (2007) reported and illustrated the defensive behavior of *D. sphingiformis.* The summary is as follows: when the moth becomes disturbed, it expands its scale tuft on the abdominal apex and starts curling its abdomen like a scorpion's stinger. This movement is continuously repeated and every curling of the abdomen is accompanied with a 'crick' stridulatory sound. This behavior of *D. sphingiformis* was also observed in Bidoup-Nui Ba National Park, Dalat City, Vietnam, and the creaking sound was clearly audible from 50 cm away (A. Kubota pers. comm., 2012).

As we observed in the field, the behavior and sound produced by *Phassus* sp. is somewhat similar to that of *D. sphingiformis.* At this moment, we speculate that the sound is produced via stridulation according to the way the moth moved its abdomen and the type of sound produced. Smetacek & Smetacek (2007) did not explain in detail the mechanism and morphological and/or anatomical structures involved in sound production by *D. sphingiformis.*

Audible stridulatory sounds produced in adult Lepidoptera are fairly uncommon compared to those ultrasonic inaudible stridulatory sounds. Further studies are worth conducting. First of all, to clarify the mechanism or the source of the sound, it is necessary to conduct careful morphological and anatomical studies of this unidentified *Phassus*, and also of related other *Phassus* species. It would be ideal to manipulate live or recently deceased, soft specimens to locate the specialized organs, e.g. stridulatory files and an amplification mechanism. In other words, examining hard and dried specimens may be less productive in finding and understanding the mechanism. For precise identification of the sound-producing *Phassus* spp., it will be very important to collect and properly preserve specimens because of the similarities in their external characters (Mielke & Grehan, 2012).

Inferring from this first short observation of a *Phassus* sp., the raising of the abdomen with the clicking sound and simultaneous presentation of structural color-like striking blue patches along the dark-colored dorsum probably have a defensive function against some natural enemies such as birds and mammals. It is also necessary to conduct further field observations; collecting and determining the sex may help understand more about the behavior of this *Phassus* sp.

It is worth noting that the blue iridescence on the abdominal dorsum is absent on pinned or dried specimens of *Phassus* spp. (Grehan, pers. comm., 2011). In this case, the blue iridescence could possibly be a type of structural color that is produced internally, i.e. beneath or within the exoskeleton/cuticle with a combination of water/moisture content, like those of many tortoise beetles (Chrysomelidae: Cassidinae) with metallic coloration when alive (Jolivet, 1994; Hull-Sanders, 2003; Vigneron *et al.*, 2007). Thus the blue iridescence is not visible or has gone unnoticed in dry specimens of *Phassus* spp. It is also possible that this iridescence may only occur in this peculiar *Phassus* species. If scales are present on the dorsum of each anterior part of the abdominal segment where the iridescence occurs, it is also worth examining the type of scales to see how the iridescence is produced.

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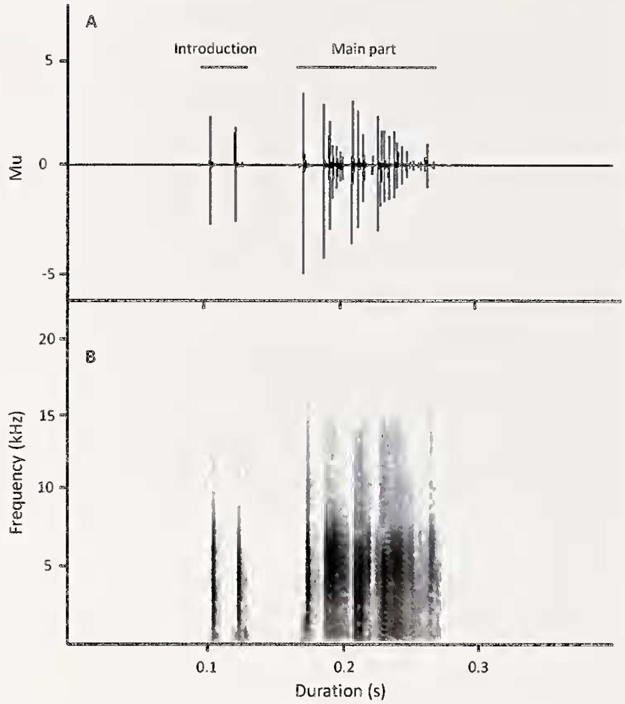

Figure 2. Visual representations of the clicking sound, introductory and main part, produced by the *Phassus* sp. A) Oscillogram, B) Sonogram.

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